BROMAN STEAM SEPARATING AND WATER CIRCULATING DEVICE

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ARMOUR INSTITUTE OF TECHNOLOGY

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WATER CIRCULATING DEVICE

A THESIS

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- INTRODUCTION -

This invention had its inception some thirty years ago when the inventor, Mr. J. G. Broman, first began his experiments to ascertain if possible the real cause of boiler explosions and thus prevent an occurrence so disastrous to life and property, a danger always present whenever steam is generated in a closed vessel.

From his numerous experiments and constant observations, extending through such a long period, not only with experimental boilers but while handling steam apparatus of all kinds as engineer in charge of large plants, he finally came to the conclusion that comparative safety from disastrous explosions can only be had by maintaining the water in a boiler in constant circulation as long as heat is applied, whether steam is drawn off the boiler or not, and in order to accomplish these results he found that a radical change from the ordinary construction was necessary.

The final results of his exhaustive labors is the patented device now known as the "Broman Steam Separating and Water Circulating Device."

Experimenting along these lines trying to perfect a device for increasing the circulation in a steam boiler to render the same safe from explosion, he found that there were other greatly beneficial results to be had from this increased circulation. It was found, for instance, that due to the workings of this device it is practically impossible for a boiler so equipped to prime or foam, as the rising mixture of steam and water is not in contact with, or passing through the body of water in the drum, as is ordinarily the case, the mixture being separated into steam and water in a separate chamber before reaching the main part of the steam drum, the dry steam passing up into the header while the water flows into the main body of water in the drum where it cannot again be agitated or disturbed but just

simply starts on a new round of circulation through the tubes.

Another beneficial result of this highly increased circulation was its preventing effect. The high velocity of the water currents not only prevents the formation of new scale but it was found that the parts directly exposed to the swift currents after a short time take the appearance of material that has just left the shop.

That such rapid circulation should result in marked increase in efficiency was to be expected and careful tests with a number of these installations have shown surprising results.

Experiments carried out by the technologic branch of the United States geological survey has proved that the heat absorbing capacity of the metal in a boiler tube or shell is practically unlimited providing there is a rapid flow of water over these surfaces and, consequently, it would be possible to overheat

the metal in a properly constructed boiler which is kept reasonably clean. Past experience, however, has shown that burnt and blistered tubes is a common occurrence whenever it is found necessary to force a boiler for any length of time considerably above rating even when clean, a sure sign that the construction of the boiler is such as not to allow free or sufficient flow of water over the heating surfaces, the restricted circulation causing steam pockets to form in the tubes or allowing the density of the mixture of steam and water to become so light as to be entirely inadequate to absorb the heat as fast as applied, resulting, of course, in damage to the material from overheating.

WIth the installation of the Broman Circulating Device, which applies to any water tube boiler now in the market, these conditions are changed, the rapid circulation set up by this device insures such a liberal supply of water to the heating surfaces that a burnt or

blistered tube is out of question and even in a case where the boilers accidently were charged with a large quantity of oil with the feed-water after this device was installed, it proved equal to the task of preventing serious damage where ruined boilers otherwise would have been the inevitable result.

As a positive relief from the trouble, worry and expense due to tube failure, priming and foaming, the value of this device to steam plant owners and operating engineers cannot be overestimated and the number of plants which have already adopted this device, although it was put on the market only recently, shows that the operating engineers realize and appreciate the fact that a badly needed improvement in the construction of water tube boilers has at last been accomplished and in such a manner as to be applicable to any water tube boiler already installed.

THE CIRCULATION OF WATER IN STEAM BOILERS.

You have all noticed a kettle of water boiling over the fire, the fluid rising somewhat tumultuously around the edges of the vessel, and tumbling toward the center, where it descends. Similar currents are in action while the water is simply being heated, but they are not perceptible unless there are floating particles in the liquid. These currents are caused by the joint action of the added temperature and two or more qualities which the water possesses.

1st. Water, in common with most other substances, expands when heated; a statement, however, strictly true only when referred to a temperature above 39 degrees F. or 4 degrees C., but as in the making of steam we rarely have to do with temperatures so low as that, we may, for our present purposes, ignore that exception.

2nd. Water is practically a non-conductor of heat, though not entirely so. If ice-cold

water was kept boiling at the surface the heat would not penetrate sufficiently to begin melting ice at a depth of 3 inches in less than about two hours. As, therefore, the heated water cannot impart its heat to its neighboring particles, it remains expanded and rises by its levity, while colder portions come to be heated in turn, thus setting up currents in the fluid.

Now, when all the water has been heated to the boiling point corresponding to the pressure to which it is subjected, each added unit of heat converts a portion, about 7 grains in weight, into vapor, greatly increasing its volume; and the mingled steam and water rises more rapidly still, producing ebullition such as we have noticed in the kettle. So long as the quantity of heat added to the contents of the kettle continues practically constant, the conditions remain similar to those we noticed at first, a tumultuous lifting of the water around the edges, flowing toward the center and thence downward; if, however, the fire be quickened, the upward

currents interfere with the downward and the kettle boils over. (Fig. 1)

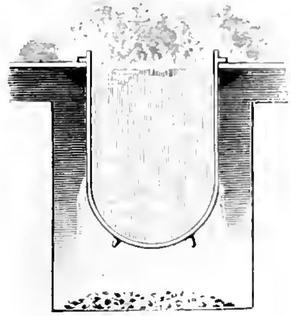


FIG. 1

Fig. 1

If now we put in the kettle a vessel somewhat smaller (Fig. 2) with a hole in the bottom and supported at a proper distance from the side so as to separate the upward from the downward currents, we can force the fires to a very much greater extent without causing the kettle to boil over, and when we place a deflecting plate so as to guide the rising column toward the center it will be almost impossible to produce that effect.

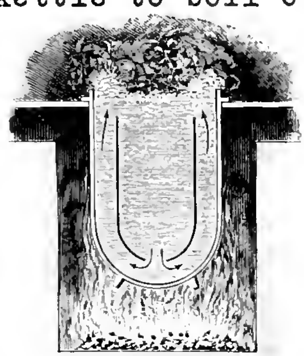


FIG. 2

Fig/ 2

But what is the object of facilitating the circulation of water in boilers? Why may we not safely leave this to the unassisted action of nature as we do in culinary operations? We may, if we do not care for the three most im-

portant aims in steam-boiler construction, namely, efficiency, durability, and safety, each of which is more or less dependent upon a proper circulation of the water. As for efficiency, we have seen one proof in our kettle. When we provided means to preserve the circulation, we found that we could carry a hotter fire and boil away the water much more rapidly than before. It is the same in a steam boiler. And we also noticed that when there was nothing but the unassisted circulation, the rising steam carried away so much water in the form of foam that the kettle boiled over, but when the currents were separated and an unimpeded circuit was established, this ceased, and a much larger supply of steam was delivered in a comparatively dry state. Thus, circulation increases the efficiency in two ways: it adds to the ability to take up the heat, and decreases the liability to waste that heat by what is technically known as priming. There is yet another way in which, incidentally, circulation increases efficiency

of surface, and that is by preventing in a greater or less degree the formation of deposits thereon. Most waters contain some impurity which, when the water is evaporated, remains to incrust the surface of the vessel. This incrustation becomes very serious sometimes, so much so as to almost entirely prevent the transmission of heat from the metal to the water. It is said that an incrustation of only one-eighth inch will cause a loss of 25 per cent in efficiency, and this is probably within the truth in many cases. Circulation of water will not prevent incrustation altogether, but it lessens the amount in all waters, and almost entirely in some, thus adding greatly to the efficiency of the surface.

A second advantage to be obtained through circulation is durability of the boiler. This it secjres mainly by keeping all parts at a nearly uniform temperature. The way to secure the greatest freedom from unequal strains in a boiler is to provide for such a circulation of the water as will insure the same temperature in all parts.

3rd. Safety follows in the wake of durability, because a boiler which is not subject to unequal strains of expansion and contraction is not only less liable to ordinary repairs, but also to rupture and disastrous explosion. By far the most prolific cause of explosions is this strain from unequal expansions.

Having thus briefly looked at the advantages of circulation of water in steam boilers, let us see what are the best means of securing it under the most efficient conditions. We have seen in our kettle that one essential point was that the currents should be kept from interfering with each other. If we could look into an ordinary return tubular boiler when steaming, we should see a curious commotion of currents rushing hither and thither, and shifting continually as one or the other contending force gained a momentary mastery. The principal upward currents would be found at the two ends, one over the fire and the other over the first

foot or so of the tubes. Between these, the donward currents struggle against the rising currents of steam and water. At a sudden demand for steam, or on the lifting of the safety valve, the pressure being slightly reduced, the water jumps up in jets at every portion of the surface, being lifted by the sudden generation of steam throughout the body of water. You have seen the effect of this sudden generation of steam in the well-known experiment with a Florence flask, to which a cold application is made while boiling water under pressure is within. You have also witnessed the geyser-like action when water is boiled in a test tube held vertically over a lamp (Fig. 3).

If now we take a U-tube depending from a vessel of water (Fig.4) and apply the lamp to one leg a circulation is at once set up within it, and no such spasmodic action can be produced.

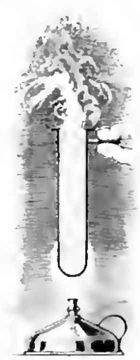


Fig.3

Thus U-tube is the representative of the true method of circulation within a water-tube boiler properly constructed.

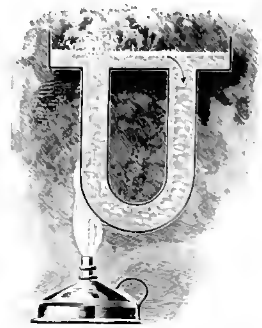


Fig.4

We can, for the purpose of securing more heating surface, extend the heated leg into a long incline (Fig.5), when we have the well-known inclined-tube generator. Now, by adding other tubes, we may further increase the heating surface (Fig.6), while it will still be the U-tube in effect and action. In such a construction the circulation is a function of the difference in density of the two columns. Its velocity is measured by the well-known Torricellian formula, $V = \sqrt{2gh}$, or, approximately, $V = 8\sqrt{h}$, h being measured in terms of the lighter fluid.

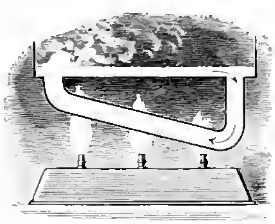


Fig.5

This velocity will increase until the rising column becomes all steam, but the quantity or weight circulated will attain a maximum when the density of the mingled steam and water in the rising column becomes one-half

that of the solid water in the descending column which is nearly coincident with the condition of half steam and half water, the weight of the steam being very slight compared to that of the water.

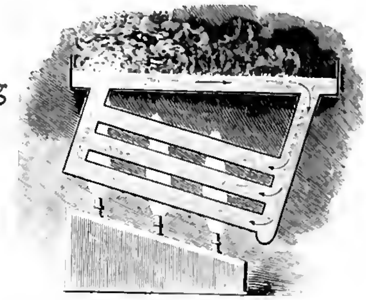


Fig.6

It becomes easy by this rule to determine the circulation in any given boiler built on this principle, provided the construction is such as to permit a free flow of the water. Of course, every bend detracts a little and something is lost in getting up the velocity, but when the boiler is well arranged and proportioned these retardations are slight.

Let us take for example a 240 horse-power Babcock & Wilson boiler. The height of the columns may be taken as 4-1/2 feet, measuring from the surface of the water to about the center of the bundle of tubes over the fire, and the head would be equal to this height at the maximum of circulation. We should, there-

fore, have a velocity of 8 $\sqrt{4\text{-}1/2}$ = 16.97, say 17 feet per second. There are in this boiler fourteen sections, each having a 4-inch tube opening into the drum, the area of which (inside) is 11 square inches, the fourteen aggregating 154 square inches, or 1.07 square feet. This multiplied by the velocity, 16.97 feet, gives 18.16 cubic feet mingled steam and water discharged per second, one-half of which, or 9.08 cubic feet, is steam. Assuming this steam to be at 100 pounds gauge pressure, it will weigh 0.258 pound per cubic foot. Hence, 2.34 pounds of steam will be discharged per second, and 8,433 pounds per hour. Dividing this by 30, the number of pounds representing a boiler horse power, we get 281.1 horse power, about 17 per cent, in excess of the rated power of the boiler/ The water at the temperature of steam at 100 pounds pressure weighs 56 pounds per cubic foot, and the steam 0.258 pound, so that the steam forms but $\frac{1}{218}$ part of the mixture by weight, and consequently each particle of water will make 218

circuits before being evaporated when working at this capacity, and circulating the maximum weight of water through the tubes.

It is evident that at the highest possible velocity of exit from the generating tubes, nothing but steam will be delivered and there will be no circulation of water except to supply the place of that evaporated. Let us see at what rate of steaming this would occur with the boiler under consideration. We shall have a column of steam, say 4 feet high on one side and an equal column of water on the other. Assuming, as before, the steam at 100 pounds and the water at same temperature, we will have a head of 866 feet of steam and an issuing velocity of 235.5 feet per second. This multiplied by 1.07 square feet of opening by 3,600 seconds in an hour, and by 0.258 gives 234,043 pounds of steam, which, though only one-eighth the weight of mingled steam and water delivered at the maximum, gives us 7,801 horse power, or 32 times the rated power of the boiler/

Of course, this is far beyond any possibility of attainment, so that it may be set down as certain that this boiler cannot be forced to a point where there will not be an efficient circulation of the water. By the same method of calculation it may be shown that when forced to double its rated power, a point rarely expected to be reached in practice, about two-thirds the volume of mixture of steam and water delivered into the drum will be steam, and that the water will make 110 circuits while being evaporated. Also that when worked at only about one-quarter its rated capacity, one-fifth of the volume will be steam and the water will make the rounds 870 times before it becomes steam. You will thus see that in the proportions adopted in this boiler there is provision for perfect circulation under all the possible conditions of practice.

In designing boilers of this style it is necessary to guard against having the uptake at the upper end of the tubes too large, for if

sufficiently large to allow downward currents therein, the whole effect of the rising column in increasing the circulation in the tubes is nullified (Fig.7). This will readily be seen if we consider the uptake very large when the only head producing circulation in the tubes will be that due to the inclination of each tube taken by itself. This objection is only overcome when the uptake is so small as to be entirely filled with the ascending current of mingled steam and water. It is also necessary that this uptake should be practically direct, and it should not be composed of frequent enlargments and contractions. Take, for instance, a boiler well known in Europe, copied and sold here under another name. It is made up of inclined tubes secured by pairs into boxes at the ends, which boxes are made to communicate with each other by return bends opposite the ends of the tubes. These boxes and return bends form an irregular uptake, whereby

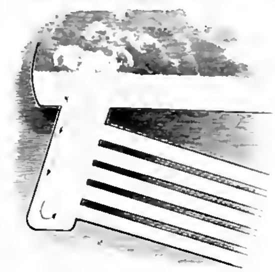


Fig.7

the steam is expected to rise to a reservoir above. You will notice (Fig.8) that the upward current of steam and water in the return bend meets and directly antagonizes the upward current in the adjoining tube. Only one result can follow. If their velocities are equal, the momentum of both will be neutralized and all circulation stopped, or, if one be stronger, it will cause a back flow in the other by the amount of difference in force, with practically the same result.

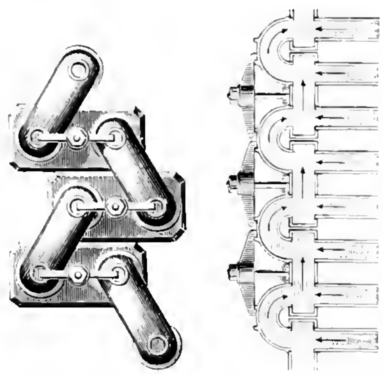

[Developed to show Circulation]

Fig.8

In a well-known boiler, many of which were sold, but of which none are now made and a very few are still in use, the inventor claimed that the return bends and small openings against the tubes were for the purpose of "restricting the circulation" and no doubt they performed well that office; but excepting for the smallness of the openings they were not as efficient for that purpose as the arrangement

shown in Fig.8.

Another form of boiler has the uptake made of boxes into which a number, generally from two to four tubes, are expanded, the boxes being connected together by nipples (Fig.9). It is a well-known fact that where a fluid flows through a conduit which enlarges and then contracts, the velocity is lost to a greater or less extent at the enlargements, and has to be gotten up again at the contractions each time, with a corresponding loss of head. The same thing occurs in the constrcution shown in Fig.9. The enlargements and contractions quite destroy the head and practically overcome the tendency of the water to circulate.

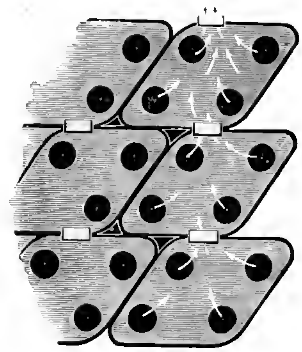


Fig.9

A horizontal tube stopped at one end, as shown in Fig.10, can have no proper circulation within it. If moderately driven, the water may struggle in against the issuing steam sufficiently to keep the surface covered, but a slight degree of forcing

will cause it to act like the test tube in Fig.3, and the more there are of them in a given boiler the more spasmodic will be its working.

The experiment with our kettle (Fig.2) gives the clue to the best means of promoting circulation in ordinary shell boilers. Steenstrup or "Martin" and "Galloway" water tubes placed in such boilers also assist in directing the circulation therein, but it is almost impossible to produce in shell boilers, by any means the circulation of all the water in one continuous round, and such as marks the well constructed water-tube boiler.

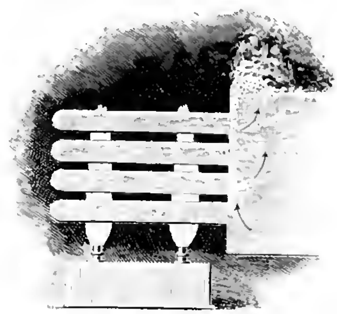


Fig.10

Provision for a proper circulation of water has been universally ignored in designing steam boilers, but by the installation of the recent invention known as the "Broman Steam Separating and Water Circulating Device" proper circulation of water is readily produced, thus increasing the efficiency, durability and safety of the boiler.

COMMENT ON WATER CIRCULATION.

The results of the study of the boiler-water circulation suggest for consideration, a feature in the construotion of the boilers. This feature, which perhaps applies to most horizontal water-tube boilers, is the advisability of large water oonnection between the water tubes and the steam drum in order that the water may pass through them freely and thus the circulation be hindered as little as possible. To make this point clear let us assume that in the average boiler the velocity of water circulation through all the tubes is sixty feet per minute at a rated capacity, perhaps that figure is not very far from the actual value. Since the total cross sectional area of the tubes is 6.7 square feet, the tubes will discharge 6.7 cubic feet of water per second into the front water leg.

Now it is plain that if the water passage from the water leg into the steam drum is two square feet in area, the belocity of the water through this passage would be over three feet per

second. This calculation does not take into account the presence of steam which greatly increases the column of the mixture, so that its velocity is perhaps double that figured above, and is sufficient to raise the water in the front of the steam drum about six inches above the normal water level. If the area of the passage is smaller and the velocity of the mixture high a water fountain may be formed in the front of the steam drum and effect the quality of steam or, on account of the increased pressure in the front water leg. The circulation in the upper rows of tubes may be reversed which is perhaps equally undesirable, inasmuch as the steam formed in these tubes always has a tendency to rise and therefore will tend to flow in the direction of the front water leg and thus retard the water circulation, as it is generally admitted that water circulation is essential to good operation of a boiler, all passages should be made such as to offer as little resistance to the circulation of the water as possible.

Explanations of the "Broman Patent Steam Separating and Water Circulating Device" applied to any type of horizontal and vertical water tube boiler for the purpose of obtaining increased boiler horse power efficiency - dry steam - lowering the temperature of the waste flue gases - prevent priming and foaming under any variation of load condition - also prevent burning and blistering of boiler tubes.

BOILERS.

The increase in boiler horse power efficiency is obtained by creating a rapid circulation of the water through the tubes, which absorbs the furnace heat units almost as fast as they are applied.

DRY STEAM

Dry steam is obtained by the upflowing steam and water not coming in direct commotional contact with the main body of water in the steam drum to cause moisture in the outflowing steam.

WASTE GAS TEMPERATURE.

Waste gas temperature to stack is reduced by the rapid circulation of the water through the tube, which absorbs the heat units and increases

the steam generating efficiency.

PRIMING & FOAMING.

Priming and foaming in boilers is caused by storage of extra heat units into the main body of water and sudden release of steam pressure, but with the "Broman Device" no extra heat units can be stored into the main body of water under any condition of operation whether steam is released from the steam drum or not.

BURNT & BLISTERED BOILER TUBES.

Burnt and blistered boiler tubes are caused by improper boiler construction and furnace installation which prevent ~~then~~ proper water circulation through the tubes to absorb the furnace heat as it is applied. With the "Broman Steam Separating and Water Circulating Device" installed, any amount of furnace heat can be applied without any damage to the tubes.

FACTOR OF SAFETY.

With the "Broman Steam Separating and Water Circulating Device" installed, no extra heat units can be stored into the main body of water to cause an expansive or explosive force.

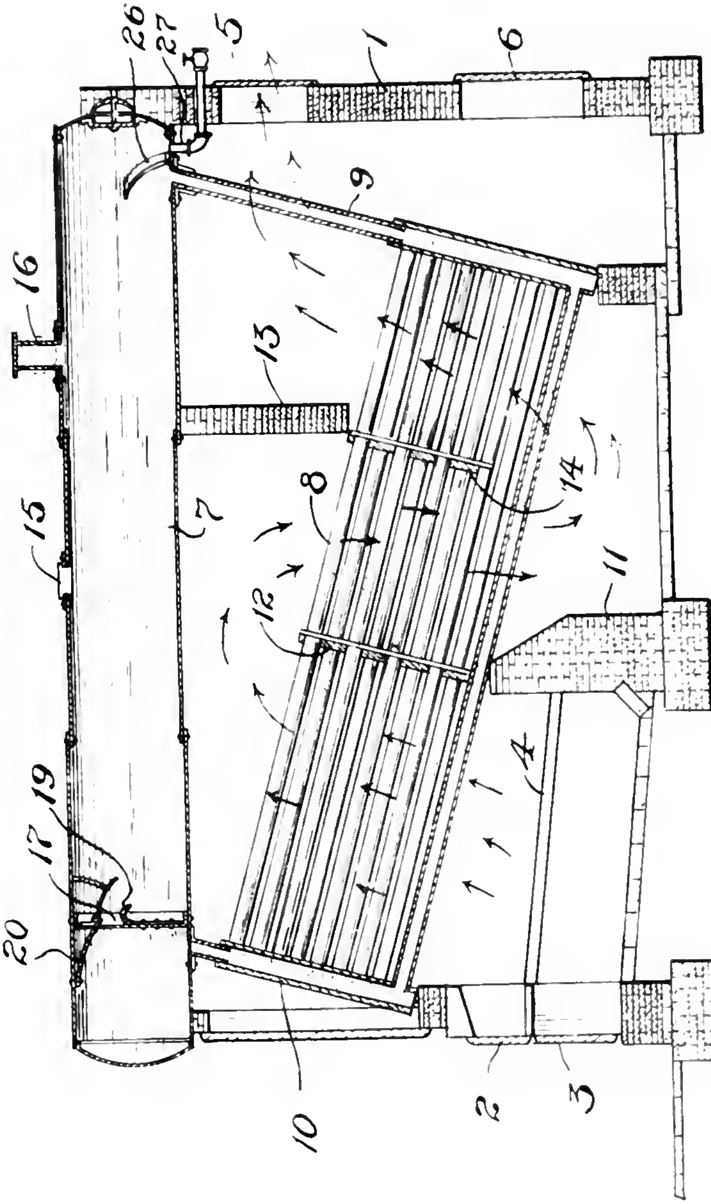


FIG. 1

Fig. 2

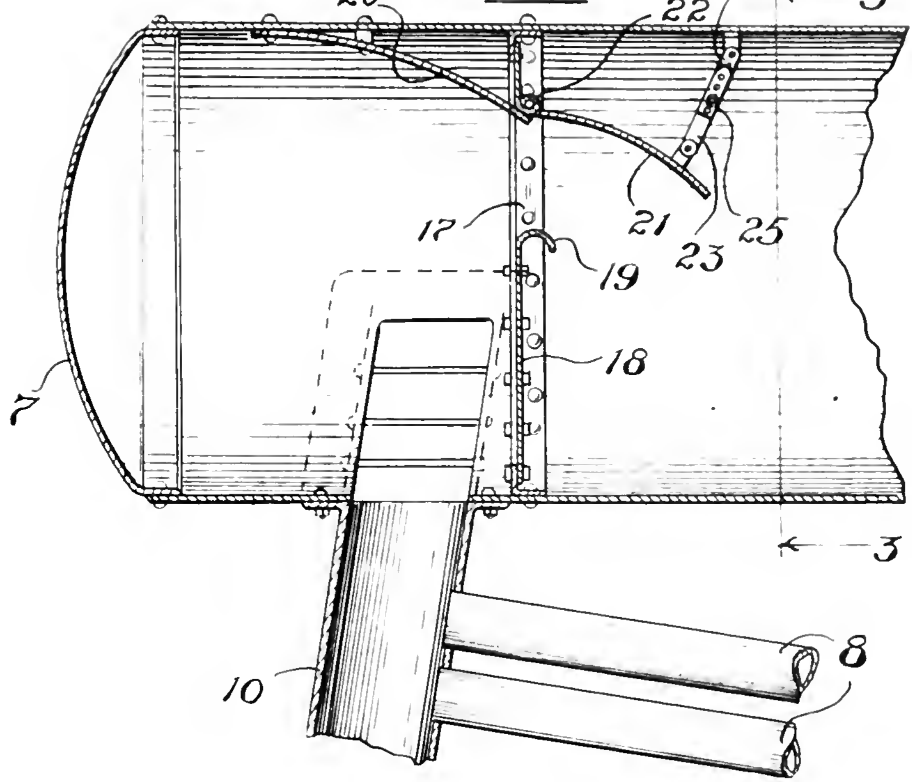


Fig. 3

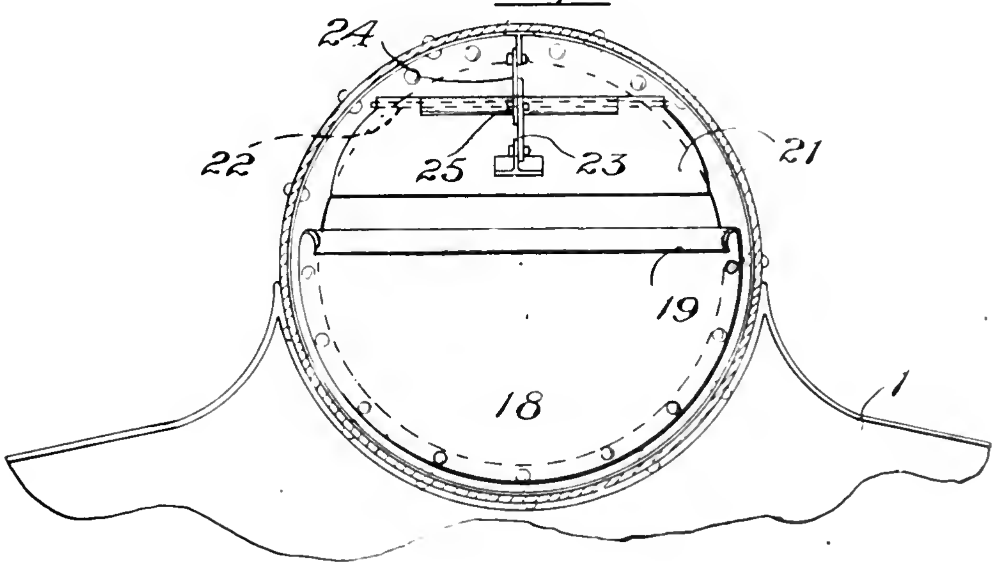


Fig. 5

Fig. 4

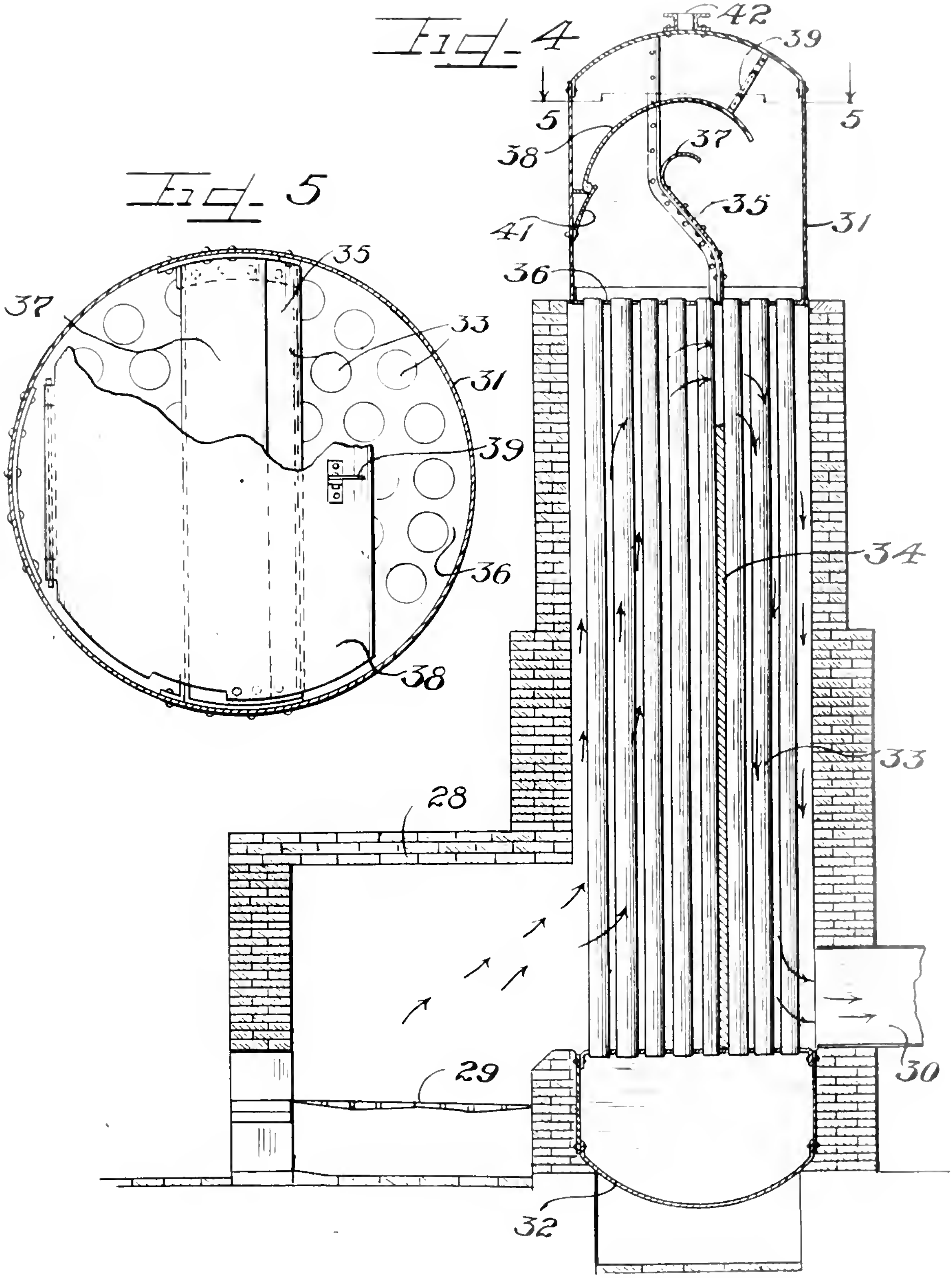


Fig. 6

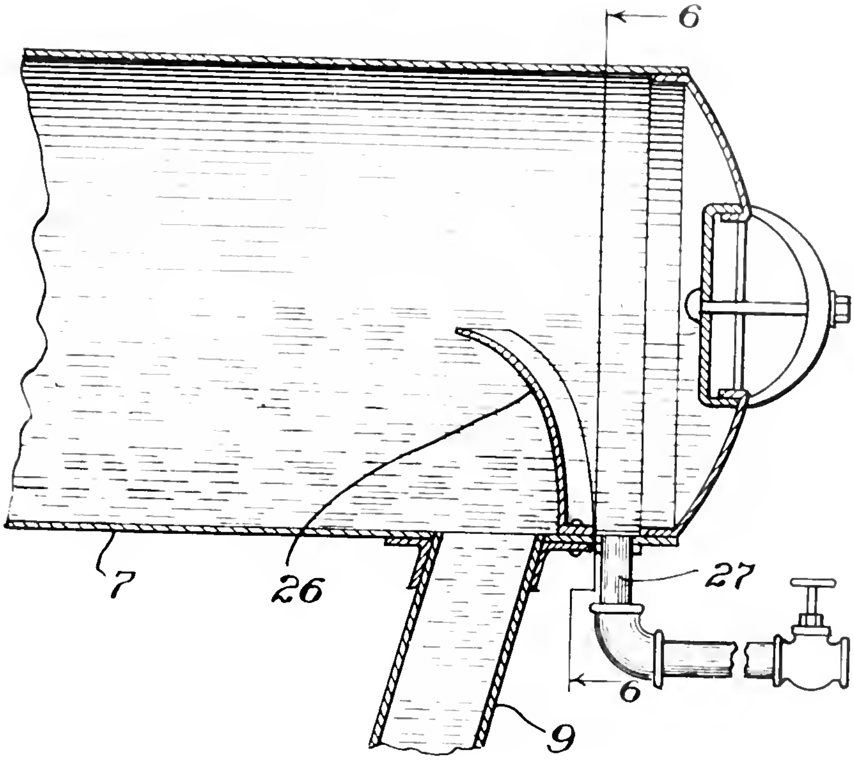
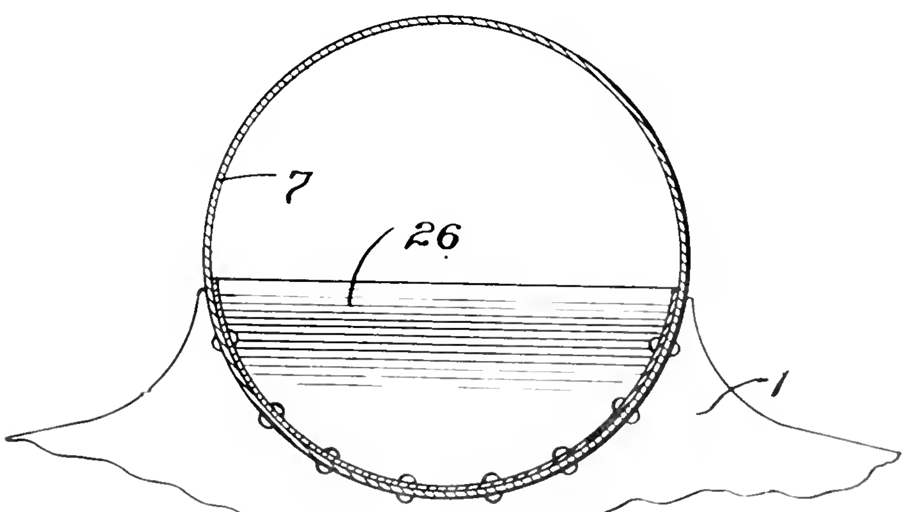


Fig. 7



DESCRIPTION AND OPERATION OF DEVICE.

Experiment has shown that the efficiency of a boiler is directly dependent upon the amount or rate of circulation of the water therethrough. In the older types of boilers the water was permitted to remain practically quiescent during heating, but, in the modern type, great is exercised in the construction to insure a rapid circulation of the water, the production of a thermo-siphon serving to promote the circulation. However, in small boilers of high horse power where the water is caused to circulate rapidly, the ebullition of steam is more or less violent, and, owing to the movement of the water throughout the boiler, foaming and priming have formed serious difficulties. In the older types of boiler where the water remains at rest while being heated, the disengagement of the steam from the water is not generally attended by any violent disturbance of the water, and with a reasonably large steam space, practically dry steam is easily obtained.

This invention relates to a boiler equipped with baffle surfaces so disposed as to form compartments effecting a partial separation of the water of different temperatures to preserve as near as possible a heating cycle. Furthermore, the steam obtained is free from entrained moisture, and the water is made to circulate rapidly through the boiler. Mechanism is also provided for collecting impurities from the surface of the water, the rapid movement of the water facilitating the operation.

The objects of this invention are as follows:

1st. To construct a boiler wherein the steam drum is partitioned to effect separation of the water of different temperatures, and further providing a chamber for the disengagement of the steam, the steam then passing into the main steam space in the steam drum, and in its passage being freed from entrained water.

2nd. To construct a boiler in which a rapid circulation of the water takes place, due to the different temperatures thereof, and in which the

rapid ebullition of steam is confined to water contained in a partitioned space communicating with the main steam space of the boiler.

3rd. To construct a boiler wherein means are provided for deflecting the circulating water in a manner to prevent undue disturbance thereof and whereby, owing to the movement of the water imputities floating on the surface may be collected or skimmed off at one point and blown out of the boiler from time to time.

4th. To construct a boiler in which the portion of the water, from which the greatest amount of the steam is evolved, is confined in one part of the boiler, but is permitted to pass into other portions of the boiler from time to time without violent disturbance, so that practically dry steam may be obtained and foaming is prevented.

5th. To provide a boiler equipped with baffle plates adapted to donfine that portion of the water from which the steam is being evolved within a certain part of the boiler, and with other baffle plates to direct the evolved steam into the main

steam space of the boiler in a manner to receive the steam from entrained water, thus preventing disturbance of the entire quantity of water in the boiler and insuring a rapid circulation thereof.

6th. To construct a boiler wherein only a small quantity of water is disturbed by the ebullition of steam and the main quantity of water is caused to circulate without foaming or priming, amd in which the evolved steam passes over the relatively quiet circulating water freed from entrained particles of moisture.

7th. To apply the principle involved in this device with very slight modification to either vertical water tube boilers or to the familiar B. and W. type, having inclined tubes.

8th. To construct the mechanism which controls the direction of flow of the water and steam, of an adjustable nature whereby the mechanism may be changed to operate properly for different water levels or for furnaces of different heating capacities.

9th. To construct mechanism adaptable to boilers

whereby the water from which the steam is disengaged may be confined temporarily in one portion of the steam drum and with adjustable means for deflecting the evolved steam into the main steam space, thereby freeing the steam from entrained particles of moisture; and with other adjustable deflecting means acting to direct the flow of the water from the steam drum of the boiler obviating disturbance of the water, and at the same time allowing the surface water to move therepast carrying the floating impurities.

10th. To construct a boiler wherein the various portions of the circulating water are temporarily maintained in different parts of the boiler, but in communication with one another, so that turbulence is avoided and circulation of the water through the boiler augmented.

The invention (in a preferred form) is illustrated in the drawings and hereinafter more fully described.

In the drawings: Figure 1 is a side elevation partly broken away, and partly in section, illustrating a B. and W. type of boiler embodying the principles of this invention. Figure 2 is an enlarged detail sectional view taken through the forward end of the steam drum. Figure 3 is a section on line 3-3 of Figure 2. Figure 4 is a central longitudinal vertical section with parts in elevation of a vertical water tube boiler embodying the principles of this invention. Figure 5 is a section on line 5-5 of Figure 4. Figure 6 is a vertical longitudinal section through the rear of the steam drum. Figure 7 is a vertical section on line 6-6 of Figure 6.

As shown in the drawings, referring to Figure 1, the boiler setting is denoted by the reference numeral 1, and is provided with a fire door 2, an ash door 3, and a grate 4. A flue passage 5, is provided in the rear wall of the setting for connection to the stack, and, a slight distance above the floor level, a soot door 6 is also mounted in said rear wall. Supported in the setting is a steam drum

7, and mounted below the same in inclined position are a plurality of water tubes 8, connected at their lower ends in a rear header 9, and at their upper ends in a front header 10, each of said headers communicating in the steam drum 7. A bridge wall 11, extends transversely of the setting at the rear of the grate 4, and built ofer said bridge wall and supporting said water tubes is a baffle wall 12. Another wall 13, arches transversely across the setting from the side walls thereof and, together with a wall 14, through which the tubes extend, affords another baffle for the products of combustion. An opening is formed in the steam drum at the point indicated by the reference numeral 15, to admit attachment of a safety valve thereto, and a steam nozzle 16 is also secured in said drum, whereby a pipe lead to the main header of a battery of boilers may be connected. An angle iron 17 is secured circumferentially around the interior of the steam drum, and secured thereto in the lower half of the drum is a semi-circular partition 18, which is turned

or curled along its upper edge as indicated by the reference numeral 19. A downwardly directed curved baffle plate 20, is rigidly secured forwardly of said angle iron ring 17, on the under side of the top wall of the steam drum, and another curved baffle plate 21, is pivotally mounted upon a rod 22, which extends transversely across said angle iron ring at end of said baffle plate 20. The outer end of the baffle plate 21, is supported by means of the links 23, and 24, respectively, which are each apertured at a plurality of points and adjustably connected by a connectin bolt 25, to permit extension of the link connection. Said link 23, is pivotally connected to the baffle plate 21, and said link 24, is likewise pivotally connected to the top wall of the steam drum. Another baffle plate 26, is fastened to the lower wall of the steam drum near the rear end thereof, and is curved to project over the point at which the rear header communicates in said drum. Directly back of said baffle plate a blow-off connection 27, is connected in the bottom of the steam drum,

so that impurities floating on the surface water will pass over the baffle plate and collect at the rear of the drum where they may settle, and be blown off from time to time.

In the construction illustrated in Figures 4 and 5, the principle of operation is exactly the same. However, in this case an upright or vertical water tube boiler is shown. The boiler setting is denoted by the reference numberal 28, and is provided, as usual, with a grate 29, and a flue duct or passage to the stack 30. Supported on the upper end of the setting is a steam drum 31, and at the lower end a water drum 32, is mounted, said steam drum and water drum being connected by a plurality of vertical water tubes 33. A baffle wall 34, extends from the water drum upwardly to a point a short distance below the steam drum, so that the products of combustion, as shown by the arrows, leaving the grate 29, pass upwardly around certain of the water tubes and downwardly around the others thereof and out at the flue duct 30. A

partition 35, extends transversely across the crown sheet 36, of the steam drum, and is secured to the side walls thereof, said partition inclining toward the front of the steam drum, and provided with a curled or turned edge 37, along its upper margin. A curved baffle plate 38, is pivotally mounted on the front wall of the steam drum, and held in position by means of links 39, and 40, respectively, adjustably connected to one another in the same manner as the links 23, and 24, already referred to in the prior construction. A stationary outwardly curved baffle plate 41, is secured on the front wall of the steam drum, and its upper edge extends to a point slightly above the pivotal connection for the adjustable baffle 38.

The operation is as follows:

Referring first to Figs. 1 to 3 inclusive, it is to be noted that the normal water level in the steam drum is slightly below the top of the curved portion 19, of the partition 18, and that furthermore the front header 10, projects upwardly a short distance through the bottom of

the steam drum. When a fire is upon the grate 4 the products of combustion first sweep upwardly around the forward ends of the water tubes, thence around and downwardly between the baffle walls 12, and 14, respectively, and finally upwardly behind the baffle walls 13, and 14, and out through the flue passage 5.

Owing to the inclination of the water tubes, a thermosiphon is set up and the water flows therethrough in the direction of the arrows. Of course, the forward ends of the tubes being subjected to the greatest heat from the furnace, and the water flowing thereinto having previously been heated at the lower ends of said tubes, a rapid ebullition of steam and flow of water takes place through the end of the front header projecting into the steam drum. Owing to the disengagement of the steam, the water contained in the steam drum forwardly of the partition 18, is in a constant state of disturbance, but the disturbance is not communicated to the main quantity of water in the steam drum on the rear side of the

partition 18. From time to time, as the level of the water on the forward side of the partition rises, the water spills over the curved upper edge thereof and then flows rearwardly with the main quantity of water in the steam drum downwardly into the rear header 9, and again upwardly through the water tubes.

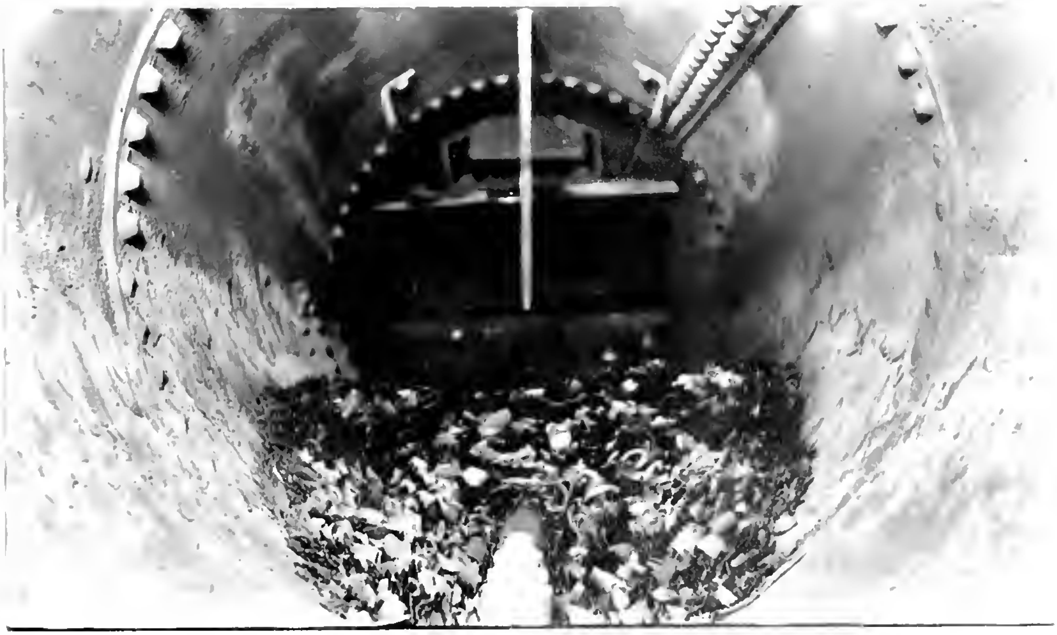
The steam evolved at the forward end of the steam drum, owing to the turbulent state of the water therein, carries more or less moisture, and accordinly the baffles 20 and 21, are provided which, as the steam flows into the main steam space in the drum, direct the same downwardly, the change in direction of flow thereof serving to throw out the particles of moisture. Owing to the realtively quiescent state of the circulating water in the main portion of the steam drum, the steam contained in the steam space thereabove is maintained in an exceedingly dry state.

There is, of course, a constant circulation of the water in the steam drum from the front to the rear thereof, and of course floating im-

purities are carried with the water. As the circulating water strikes the baffle 26, it is directed downwardly into the rear holder 9, and, owing to the fact that the baffle 26, does not extend above the surface of the water, the impurities by their own inertia are carried or skimmed thereover and then settle in the compartment behind the baffle, and are blown off from time to time, as desired, through the blow-off 27.

In the construction illustrated in Figs. 4, and 5, the principle of operation is identical with that already described. In this vertical type of boiler the steam is evolved in front of the partition 35, and as it flows upwardly after its disengagement from the surface if the water, strikes the curved deflector 38, which re-directs the steam downwardly again on the rear side of the partition 35, the change in direction of flow thereof serving to throw out the particles of entrained moisture, and the steam then passes upwardly into the steam space above the defelctor 38, in an exceedingly dry state. The

deflector 38, also serves to prevent water foaming in the steam drum into the steam nozzle, which may be connected in at the point 42.

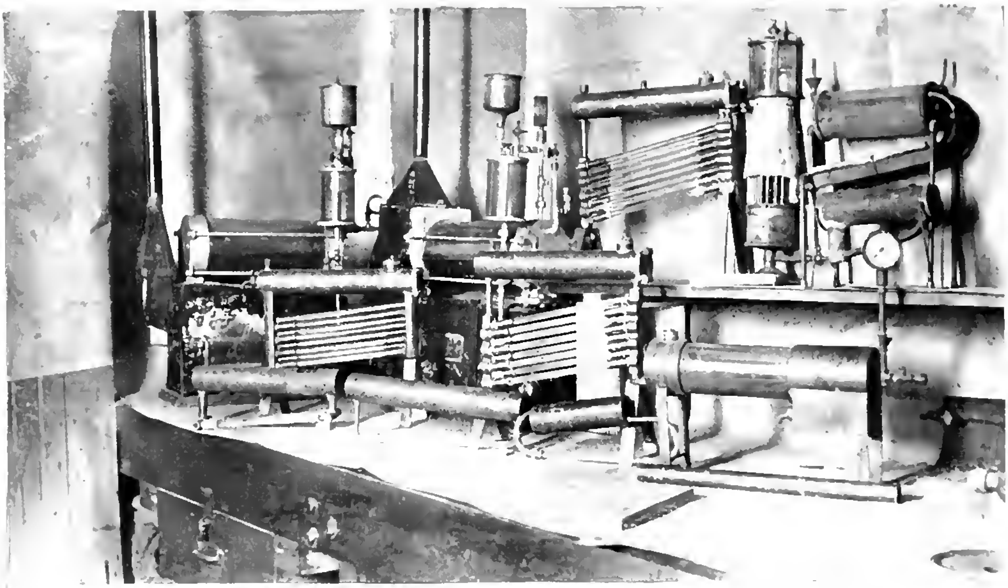


The photograph on the opposite page is taken from the drum of a Horizontal Water Tube Boiler, and shows the scale that was carried up into the drums from tubes and water legs by the rapid oirulation in this boiler after the same was equipped with the "Broman Steam Separating and Water Circulating Device."

Ordinarily the circulation in this type of boiler when working at normal rating is about 300 ft. per minute in the lowest row of tubes, this circulation diminishing rapidly in the successive upper rows, the top rows showing hardly any circulation at all according to tests and experiments carried out by the technologic branch of the United States Geological Survey, Bulletin 23. This will give an average velocity of water through all the tubes combined in this type of boiler of about sixty feet per minute, and the combined area of the tubes being about the same as that of the water legs, the flow of the mixture of steam and water upwards in the front leg cannot be much over twice this or two

feet per second if we assume this mixture to be half steam and half water which would be about correct when boiler is working at normal rating, a velocity entirely too low to carry any of the heavier scales up into the drum. As ordinarily constructed the large water leg in front on most of similar type of boilers, nullifies the effect of the rising mixture in this leg towards any increase of circulation, which in such a case depends only on the pitch of the tubes and the density or amount of steam generated in these tubes, the function of the front water leg being only to discharge into the drum whatever mixture flows out of the tubes.

With the "Broman Steam Separating and Water Circulating Device," however, the velocity of flow depends not only on the circulation set up in the individual tubes but is accelerated by the difference in density of the fluid in the rear and front leg, the formula for calculating the velocity $V = \sqrt{2gh}$ applying to the whole boiler where the device is installed instead of only to the pitch of the tube in the ordinary construction.



Experimental Boilers used in perfecting the invention known as "The Broman Steam Separating and Water Circulating Device."

TESTS.

The comparative test of two "Geary" Water Tube Boilers located in the modern power plant of the Griess Pfleger Tanning Company, Chicago, shows the following results:

The two boilers known as No.3 and No.4 are set in the same battery, have the same nominal rating of 410 H.P. each and are identical as to construction, baffling and furnaces with the exception that No.4 boiler is equipped with the "Broman Steam Separating and Water Circulating Device."

The test was made to determine only the temperature of the furnace gases on leaving the boiler heating surface and the quality of the steam delivered to the header by the boiler equipped with "Broman Separating and Circulating Device."

The lead and operating conditions were carried as nearly alike as practical and the temperature readings in the uptake of the respective boilers was taken in exactly the same location, on a center line between the two drums and about eight inches above these drums.

Results.	Boiler #3.	Boiler #4.
Average steam pressure	132#	130#
Average H.P. developed	710 H.P.	820 H.P.
Average gas temperature	654 F.	480 F.
Per cent moisture in steam		0.71%
Average CO_2 in gases	11%	10-1/2%

With an average coal consumption in this plant of about 28 tons in 24 hours the reduction in temperature of the gases alone accomplished by installing the "Broman Steam Separating and Water Circulating Device" amounts to a saving in fuel in this instance of about 4600 pounds of coal per day or 8.3%, the calculations being based on the average CO_2 per centage during the test and a heat value of the coal of about 11500 B.T.U.

The test made to determine the quality of steam delivered by one "Geary" Water Tube Boiler equipped with the "Broman Steam Separating and Water Circulating Device" gave the following results:

The boiler, one of a battery of four and located in the power plant of the Griess Pfleger Tanning Company is equipped with McKenzie chain grate stoker, is vertically baffled and has a nominal rating of 410 H.P.

Time	Steam Pressure (Gauge)	Boiler H.P. Developed	Height of Water in Steam-drum	Percentage of Moisture.
2:30 P.M.	140 Lbs.	794	1" above center	0.89%
2:32 "	134 "	800	1/2" " "	0.85%
2:35 "	127 "	822	Center of drum	0.80%
2:37 "	122 "	820	1/2" below cent.	0.75%
2:40 "	119 "	820	1" " "	0.80%
2:42 "	118 "	803	1" " "	0.80%
2:45 "	123 "	733	Center of drum	0.83%
2:47 "	126 "	660	1" above center	0.83%
2:50 "	130 "	635	2" " "	0.90%

The water columns on these boilers are set rather high and from all indications there is no

doubt but what the moisture could be reduced to less than one-half of one per cent under any lead condition if the water column was lowered so as to carry the water level a few inches below center of drum at all times.

Test made on one 300 Horse Power Geary Boiler, containing the Broman Steam Separating and Water Circulating Device at Boyd-Lunham Company, Stock Yards, Chicago, Ill/, June 10th, 1913.

Coal used....Shellbark screenings at $1.85 per ton.

Duration of test........................8 Hours

Lbs. of water evaporated from and at 212.....................................143,909

Weight of coal burned.................. 20,238

Per Hour............................. 2,529

Average Steam Pressure................... 115

Feed Water Temperature................... 206

Weight of ash.............................4,087

% of ash................................. 20%

Average Evap. % of coal from and at 212 7.11%

Average Horse Power developed............ 521

Highest H. P. rating..................... 608

Temperature of steam..................... 365

Moisture in steam of Pr. Ellison Colirometer..........................34-1/2 of 1%

Flue gas temperature..................... 550

% above boiler H.P. rating from.... 73-6/10 to 100%

TEST NO. ________

DATA AND RESULTS OF EVAPORATIVE TEST

ILLINOIS MAINTENANCE CO.

1. Test of No. 2 Boiler located at Baltimore Plant
To determine Efficiency after installing circulator.
Test conducted by Butler, Henline & Wilson
Date October 28th, 1915.

DIMENSIONS, PROPORTIONS, ETC.

2. Number and kind of boilers One - Heine
3. Kind of furnace Illinois stoker chain grate
4. Grate surface: Width 9 ft. Length 8 ft. Area 72 Sq. Ft.
5. Water heating surface, sq. ft. 3800.
6. Duration of test, hours 8.
7. Kind and size of coal No. 4 washed nut Carterville (Consumers Co.)

AVERAGE PRESSURES, TEMPERATURES, ETC.

8. Steam pressure by gauge, pounds 95
9. Force of draft at damper, inches of water 0.40
10. Force of draft in furnaces, inches of water 0.17
11. Temperature of feed water entering boilers, deg. Fahr. 128.
12. Temperature of gases leaving boilers, deg. Fahr. 735
13. Temperature of furnace, deg. Fahr.
14. Percentage of moisture in steam 1.0

TOTAL QUANTITIES

15. Weight of coal as fired, pounds 16200.
16. Percentage of moisture in coal 8.0
17. Total weight of dry coal consumed, pounds 14904.
18. Total ash and refuse, pounds 1345.
19. Total combustible consumed (Item 17—Item 18), pounds 13559.
20. Percentage of ash and refuse in dry coal 9.02
21. Total weight of water fed to boiler, pounds 123400.
22. Total water evaporated, corrected for moisture in steam, pounds 123057.
23. Factor of evaporation, based on temperature of feed water 1.1254
24. Total equivalent evaporation from and at 212°, pounds 138488.

HOURLY QUANTITIES AND RATES

25. Coal consumed per hour as fired, pounds 2025.
26. Dry coal consumed per hour, pounds 1863.
27. Combustible consumed per hour, pounds 1695.
28. Dry coal consumed per square foot of grate surface per hour, pounds 25.9
29. Water evaporated per hour, corrected for quality, pounds 15382.
30. Equivalent evaporation per hour, from and at 212°, pounds 17311.

ANALYSIS AND CALORIFIC VALUE OF COAL

1.	Moisture, per cent — Laboratory No. 1394	8.0
2.	Ash, per cent — Commercial	8.6
3.	Calorific value of 1 pound of coal as fired, B. t. u.	12164.
4.	Calorific value of 1 pound of dry coal by calorimeter, B. t. u.	13222.
5.	Calorific value of 1 pound of combustible by calorimeter, B. t. u.	14466.

CAPACITY

6.	Boiler horsepower developed, Bl. H. P.	497.
7.	Rated boiler horsepower, Bl. H. P.	380.
8.	Percentage of rated capacity developed	138.8

ECONOMY RESULTS

9.	Water fed per pound of coal (Item 21÷Item 15), pounds	7.67
0.	Water evaporated per pound of dry coal (Item 22÷Item 17), pounds	8.26
1.	Equivalent evaporation from and at 212° per pound of coal as fired (Item 24÷Item 15), pounds	8.55
2.	Equivalent evaporation from and at 212° per pound of dry coal (Item 24÷Item 17), pounds	9.29
3.	Equivalent evaporation from and at 212° per pound of combustible (Item 24÷Item 19), pounds	10.21

EFFICIENCY

4.	Efficiency of boiler, furnace and grate, $100 \times \frac{\text{Item } 42 \times 970.4}{\text{Item } 34}$ per cent.	68.18
5.	Efficiency of boiler and furnace, $100 \times \frac{\text{Item } 43 \times 970.4}{\text{Item } 35}$ per cent.	68.5

COST OF EVAPORATION

6.	Cost of coal per ton of 2000 pounds delivered in boiler room	$ 2.84
7.	Cost of coal required for evaporating 1000 pounds of water under observed conditions	$ .185
8.	Cost of coal required for evaporating 1000 pounds of water from and at 212°	$ .166

SMOKE DATA

9.	Percentage of smoke as observed	
0.	Number of violations	
1.	Average duration of each violation	

ANALYSIS OF DRY GASES BY VOLUME

2.	Carbon dioxide (CO_2) per cent	8.6

REMARKS

Ash:

Moisture 8.8%

Combustible 5.8%

TEST NO. 2

DATA AND RESULTS OF EVAPORATIVE TEST

ILLINOIS MAINTENANCE CO.

1. Test of No. 2 Boiler located at Baltimore Plant
To determine Efficiency before installing circulator.
Test conducted by Butler & Henline.
Date October 12th, 1915.

DIMENSIONS, PROPORTIONS, ETC.

2.	Number and kind of boilers	One-Heine.
3.	Kind of furnace	Illinois Stoker Chain Grate
4.	Grate surface: Width 9 ft. Length 8 ft. Area	72 Sq. Ft.
5.	Water heating surface, sq. ft.	3800
6.	Duration of test, hours	8
7.	Kind and size of coal	No. 4 Washed Nut Carterville, (Consumers Co.)

AVERAGE PRESSURES, TEMPERATURES, ETC.

8.	Steam pressure by gauge, pounds	96
9.	Force of draft at damper, inches of water	0.42
10.	Force of draft in furnaces, inches of water	0.15
11.	Temperature of feed water entering boilers, deg. Fahr.	141/
12.	Temperature of gases leaving boilers, deg. Fahr.	752.
13.	Temperature of furnace, deg. Fahr.	---
14.	Percentage of moisture in steam	2.

TOTAL QUANTITIES

15.	Weight of coal as fired, pounds	16300.
16.	Percentage of moisture in coal	8.0
17.	Total weight of dry coal consumed, pounds	14996.
18.	Total ash and refuse, pounds	---
19.	Total combustible consumed (Item 17—Item 18), pounds	---
20.	Percentage of ash and refuse in dry coal	---
21.	Total weight of water fed to boiler, pounds	116132.
22.	Total water evaporated, corrected for moisture in steam, pounds	113809.
23.	Factor of evaporation, based on temperature of feed water	1.1122
24.	Total equivalent evaporation from and at 212°, pounds	126578.

HOURLY QUANTITIES AND RATES

25.	Coal consumed per hour as fired, pounds	2037.5
26.	Dry coal consumed per hour, pounds	1874.5
27.	Combustible consumed per hour, pounds	---
28.	Dry coal consumed per square foot of grate surface per hour, pounds	26.0
29.	Water evaporated per hour, corrected for quality, pounds	14226.
30.	Equivalent evaporation per hour, from and at 212°, pounds	15822.

ANALYSIS AND CALORIFIC VALUE OF COAL

31. Moisture, per cent 8.0
32. Ash, per cent 9.9
33. Calorific value of 1 pound of coal as fired, B. t. u. .... 11915.
34. Calorific value of 1 pound of dry coal by calorimeter, B. t. u. .... 12951.
35. Calorific value of 1 pound of combustible by calorimeter, B. t. u. .... 14374.

CAPACITY

36. Boiler horsepower developed, Bl. H. P. .... 459.
37. Rated boiler horsepower, Bl. H. P. .... 380.
38. Percentage of rated capacity developed 120.8

ECONOMY RESULTS

39. Water fed per pound of coal (Item 21÷Item 15), pounds 7.12
40. Water evaporated per pound of dry coal (Item 22÷Item 17), pounds 7.59
41. Equivalent evaporation from and at 212° per pound of coal as fired (Item 24÷Item 15), pounds 7.77
42. Equivalent evaporation from and at 212° per pound of dry coal (Item 24÷Item 17), pounds 8.44
43. Equivalent evaporation from and at 212° per pound of combustible (Item 24÷Item 19), pounds .... ----

EFFICIENCY

44. Efficiency of boiler, furnace and grate, $100 \times \frac{\text{Item 42} \times 970.4}{\text{Item 34}}$ per cent. 63.2
45. Efficiency of boiler and furnace, $100 \times \frac{\text{Item 43} \times 970.4}{\text{Item 35}}$ per cent. .... ----

COST OF EVAPORATION

46. Cost of coal per ton of 2000 pounds delivered in boiler room .... $ 2.84
47. Cost of coal required for evaporating 1000 pounds of water under observed conditions .... $ .199
48. Cost of coal required for evaporating 1000 pounds of water from and at 212° .... $ .183

SMOKE DATA

49. Percentage of smoke as observed ....
50. Number of violations ....
51. Average duration of each violation ....

ANALYSIS OF DRY GASES BY VOLUME

52. Carbon dioxide (CO_2) per cent 8.7

REMARKS

Analysis of refuse
Moisture 18.5%
Combustible 11.6%

Water meter #1368 was used for measuring feed water.

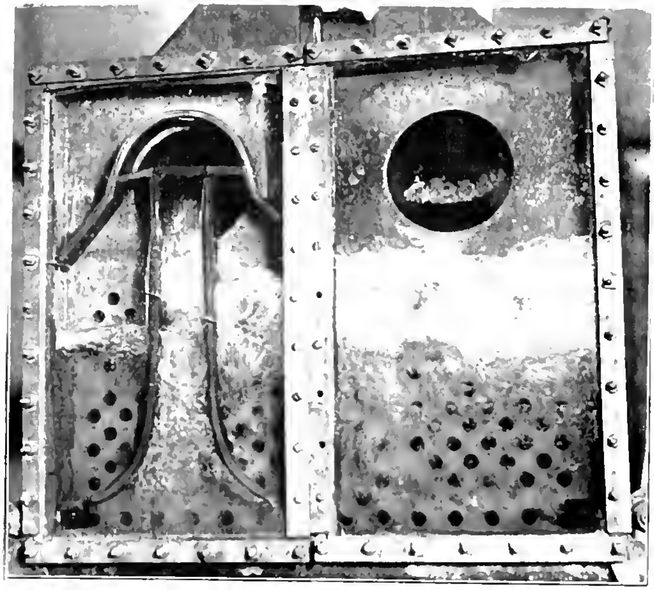
CONCLUSIONS OF TESTS MADE BY THE A.S.M.E.

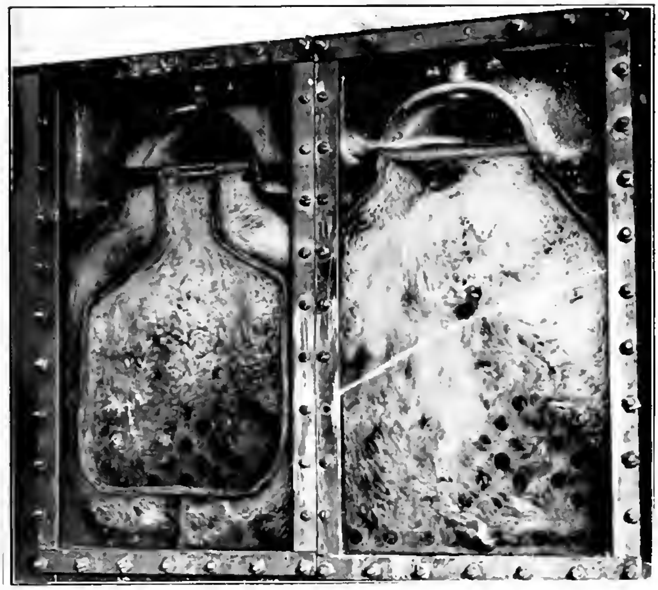
Increased circulation in the lower rows of tubes of a horizontal boiler can be obtained by constructions which segregate the discharge from those tubes up through the front header into the drum, and by designing the circuit to prevent slip and to offer the least resistance, particularly at the entrance to the drum.

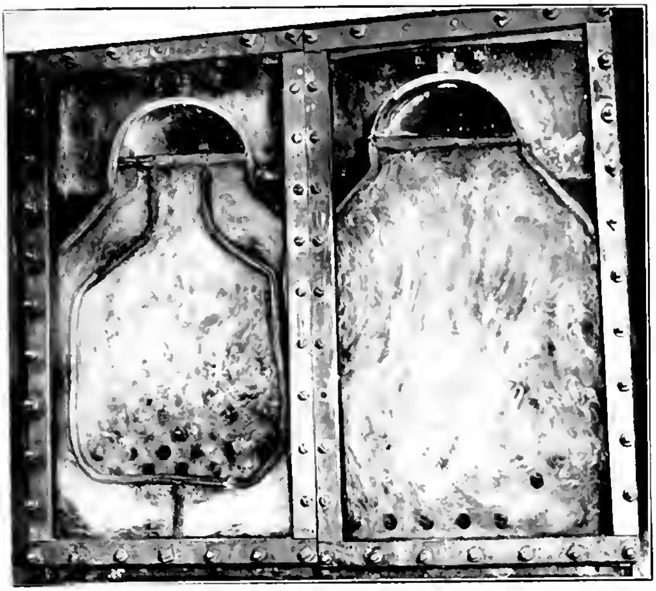
The velocity of circulation of a steam-water mixture increases about as the square root of the steam volume or load.

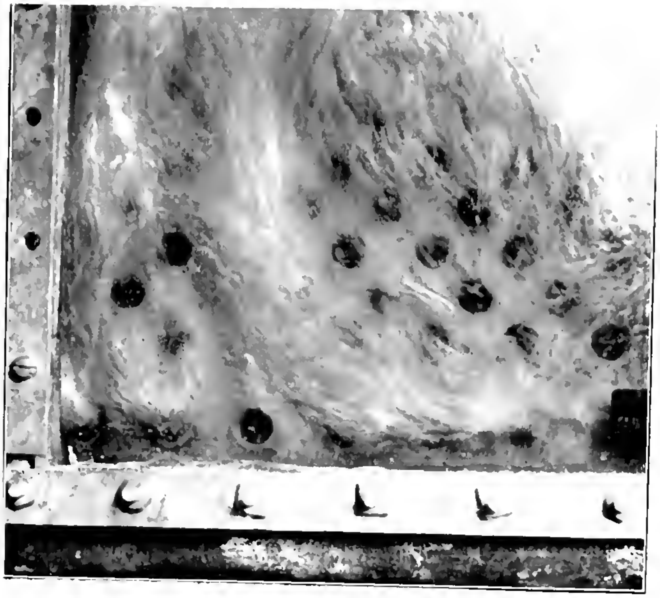
The volume of water circulated increases at first as the steam volume increases, reaches a maximum, and then decreases. The maximum load on a tube should not exceed that coincident with maximum water delivery.

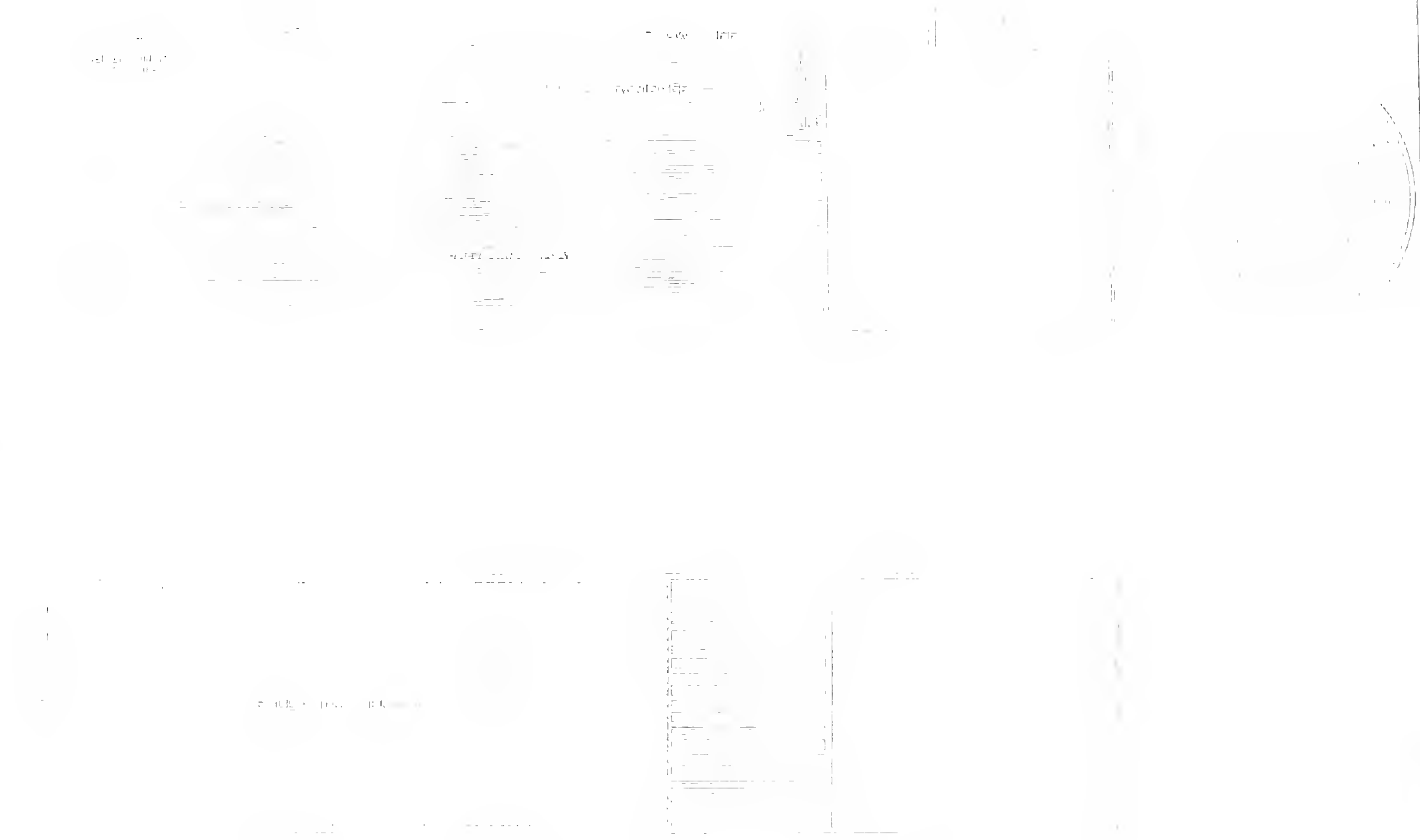
The tendency for reversal of circulation is lessened by setting the boiler so that the gases strike the tube bank at its higher end.



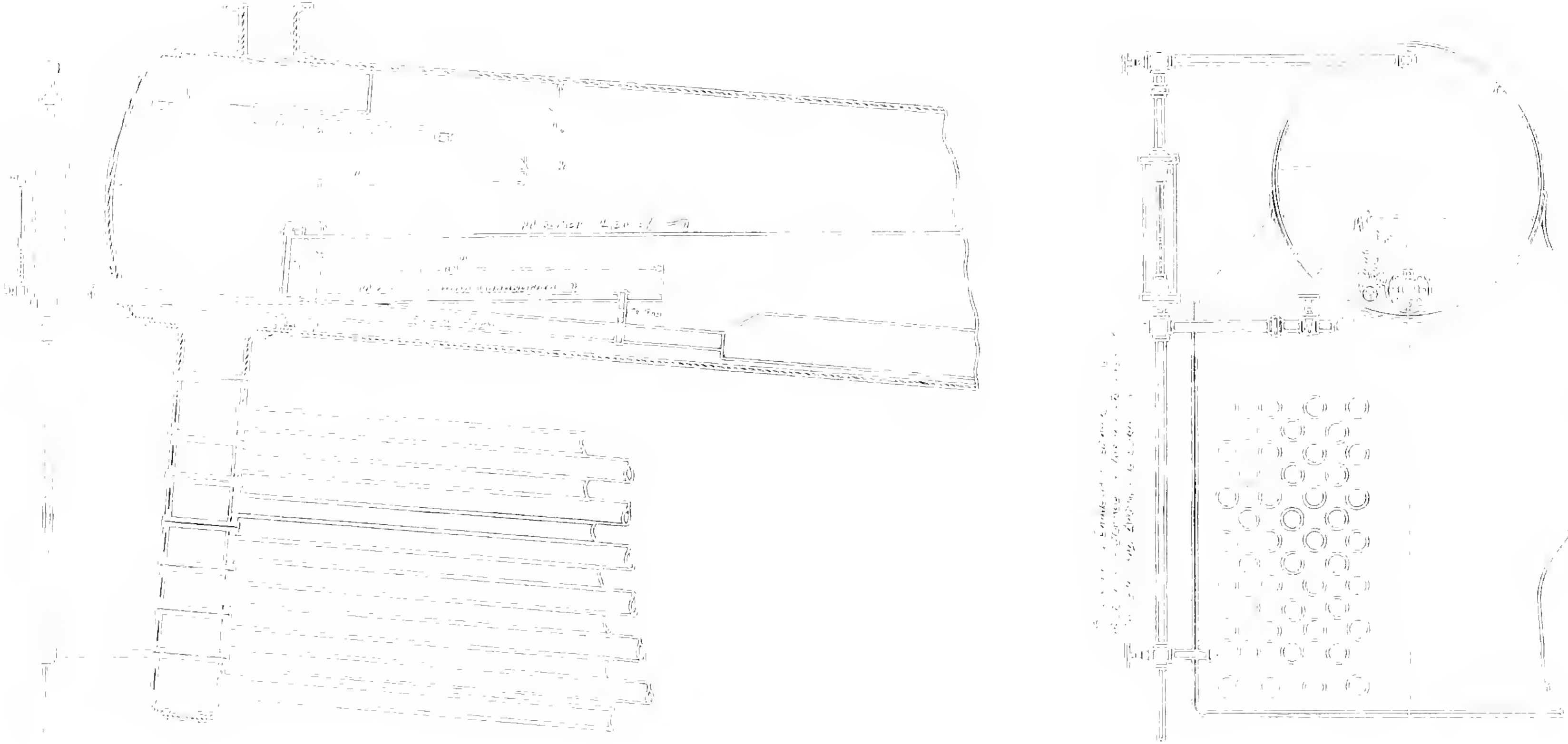








DEVICE

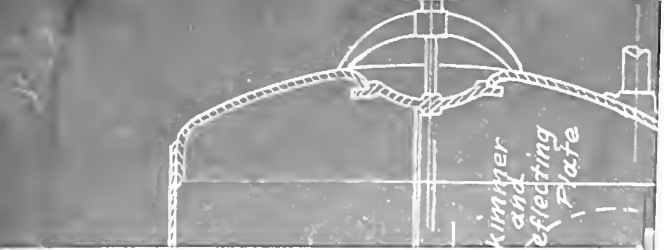


of Heine Water Tube Boiler

Scale 3/4" = 1 Ft.

BROMAN AND SON.

CHICAGO, ILL.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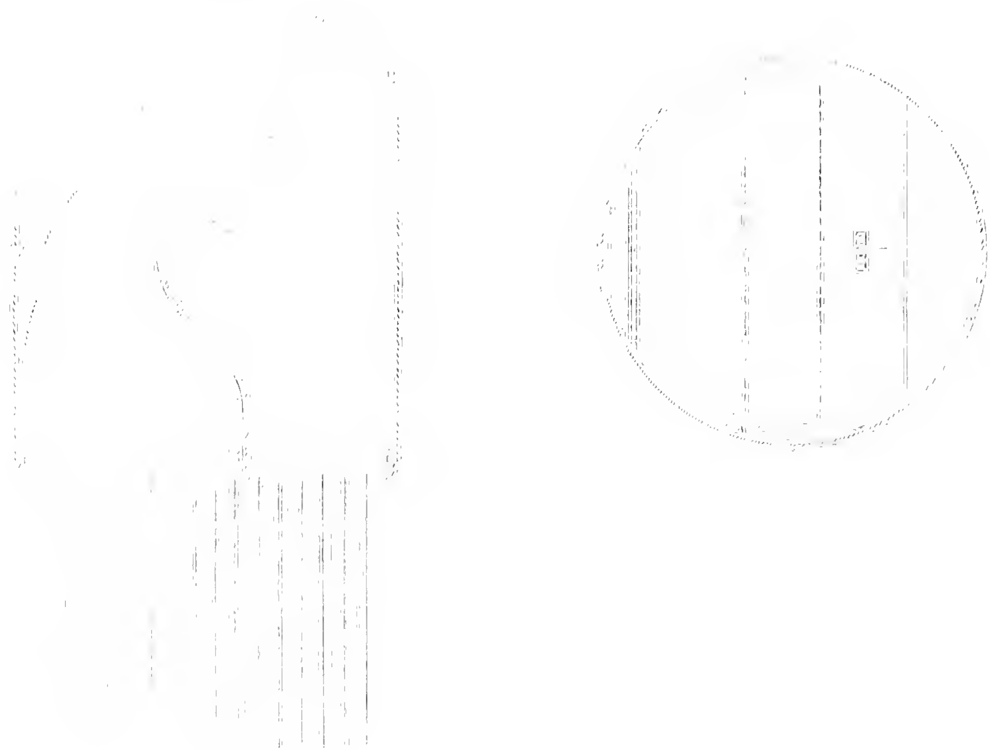

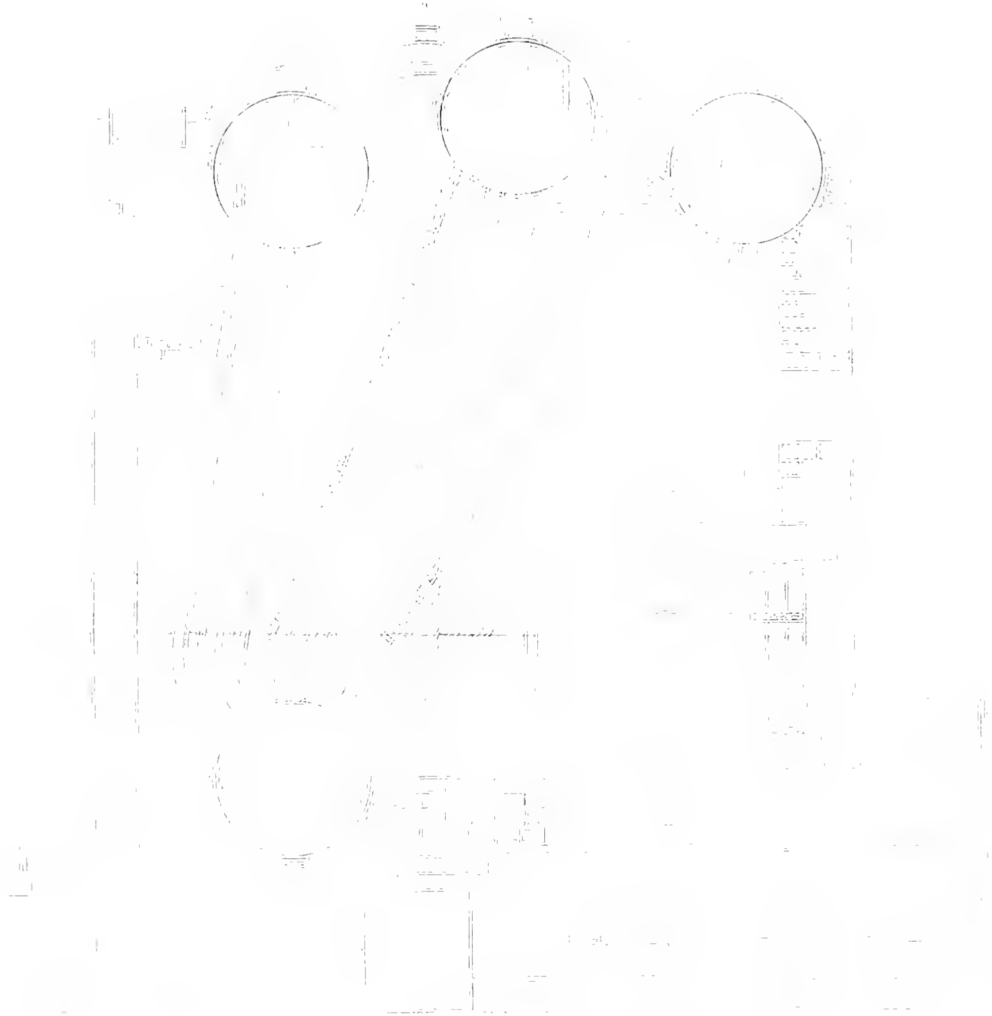

"BROMAN"

STEAM SEPARATING

and

WATER CIRCULATING DEVICE

APPLIED TO ... BOILER